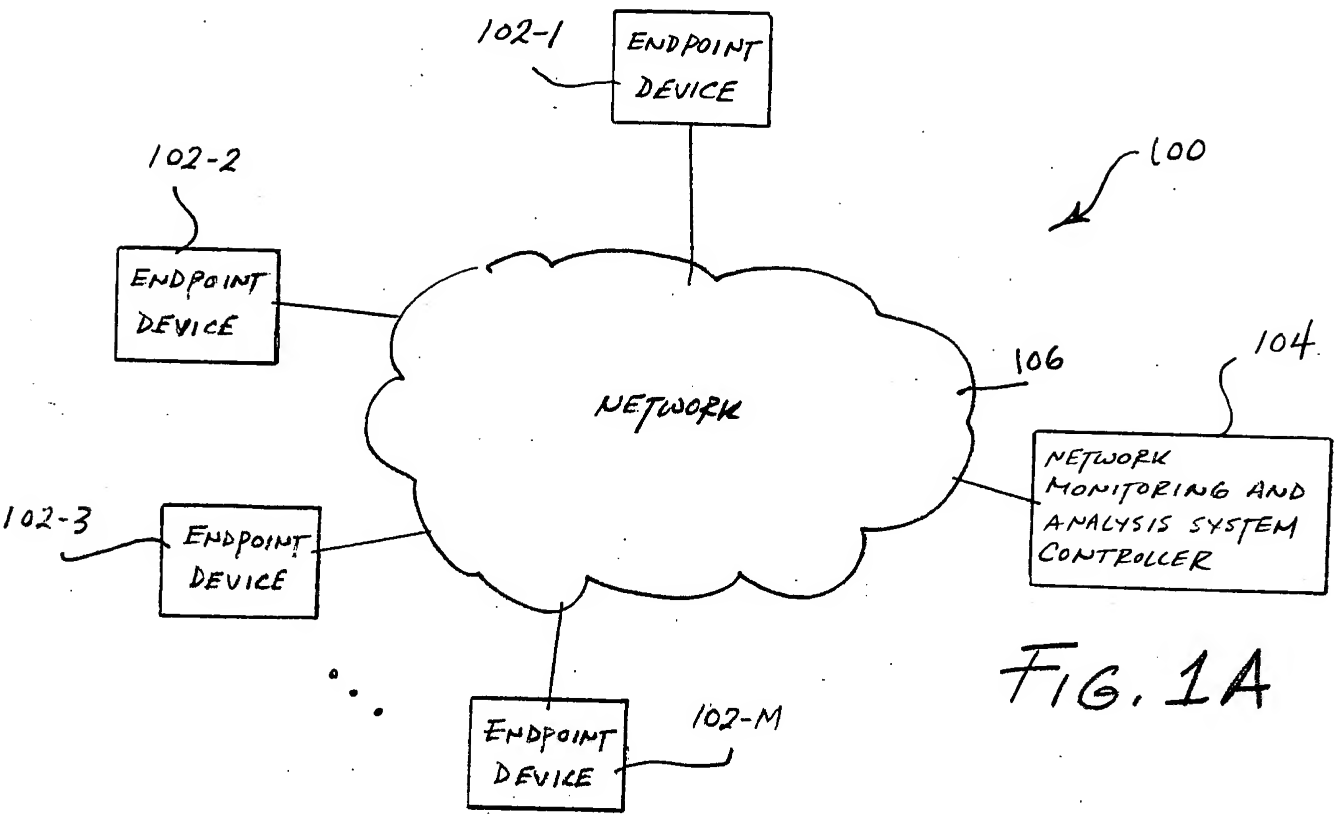

102-1
ENDPOINT
DEVICE
100
102-2
ENDPOINT
DEVICE
NETWORK
106
104
NETWORK
MONITORING AND
ANALYSIS SYSTEM
CONTROLLER
102-3
ENDPOINT
DEVICE
ENDPOINT
DEVICE
102-M

FIG. 1A

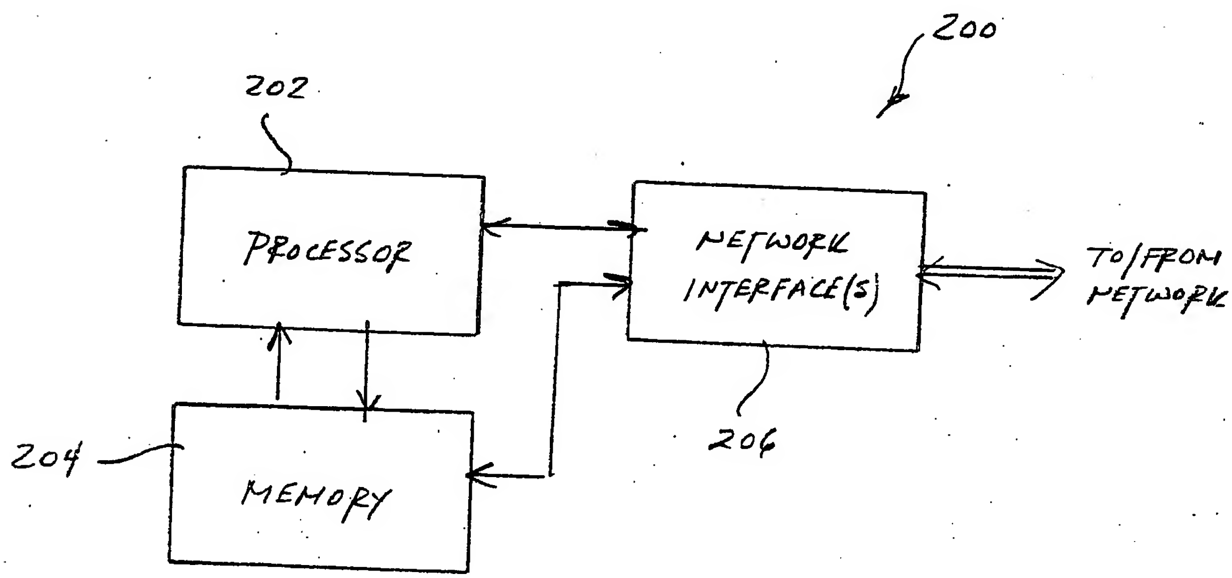

200
202
PROCESSOR
NETWORK
INTERFACE(S)
TO/FROM
NETWORK
204
MEMORY
206

FIG. 1B

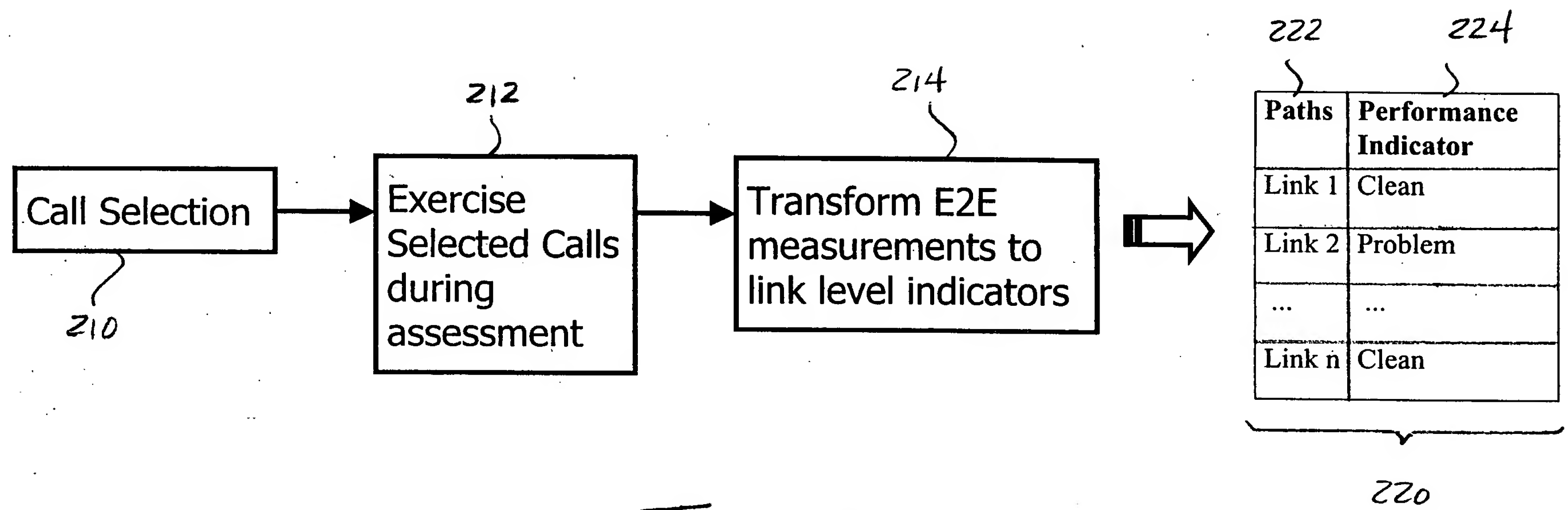

Call Selection
210
Exercise Selected Calls during assessment
212
Transform E2E measurements to link level indicators
214
222
224
Paths
Performance Indicator
Link 1
Clean
Link 2
Problem
...
...
Link n
Clean
220

FIG. 2A

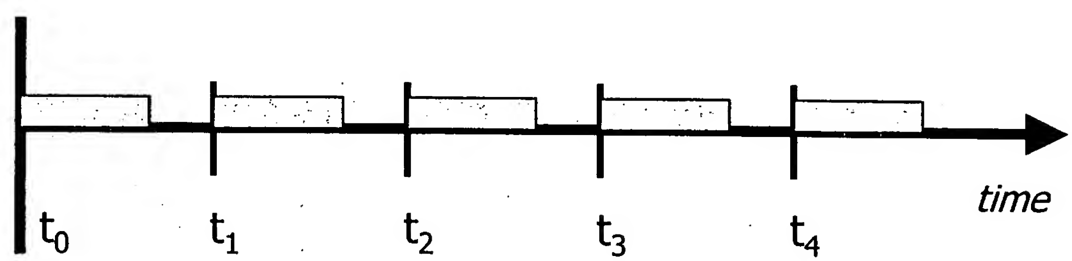

t_0
t_1
t_2
t_3
t_4
time

FIG. 2B

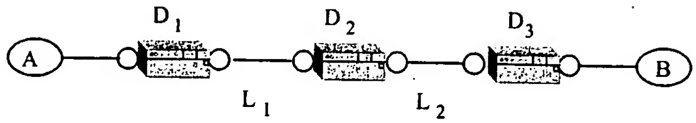


FIG. 3

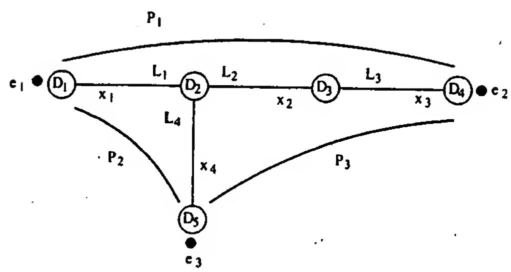


FIG. 4

$$\begin{array}{c|cccc} & L_1 & L_2 & L_3 & L_4 \\ \hline P_1 & 1 & 1 & 1 & 0 \\ P_2 & 1 & 0 & 0 & 1 \end{array}$$

Flow matrix 1

$$\begin{array}{c|cccc} & L_1 & L_2 & L_3 & L_4 \\ \hline P_1 & 1 & 1 & 1 & 0 \\ P_2 & 1 & 0 & 0 & 1 \\ P_3 & 0 & 1 & 1 & 1 \end{array}$$

Flow matrix2

FIG. 5

Equations with Flow matrix 1

$$\begin{aligned} x_1 + x_2 + x_3 &= y_1 \\ x_1 + x_4 &= y_2 \end{aligned} \qquad \begin{bmatrix} 1 & 1 & 1 & 0 \\ 1 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} = \begin{bmatrix} y_1 \\ y_2 \end{bmatrix}$$

Equations with Flow matrix 2

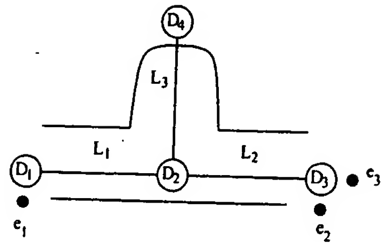
$$\begin{aligned} x_1 + x_2 + x_3 &= y_1 \\ x_1 + x_4 &= y_2 \\ x_2 + x_3 + x_4 &= y_3 \end{aligned} \qquad \begin{bmatrix} 1 & 1 & 1 & 0 \\ 1 & 0 & 0 & 1 \\ 0 & 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} = \begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix}$$

FIG. 6

Generate_Pipes($G = (D, L)$:Network Topology Graph, E: Set of Leaves)

I: Set of pipes in G wrt E
$I \leftarrow \emptyset$
Compute P for G wrt E
Let M be the complete flow matrix for G and P
// Group links with the same column vector into disjoint sets
Let k be the number of distinct column vectors in M
Form a set $\mathbf{S} = \{S_0, S_1, ..., S_k\}$ where :
    each $S_i, 0 < i \leq k$ contains links in L with the i^{th} distinct column vector in M
// Ensure that links in each element of **S** *form a path in G*
for i=1 to $|\mathbf{S}|$
    if links in S_i are consecutive and form a path
        then merge S_i into path p, $I \leftarrow I \cup \{p\}$ *// add the path formed by the links in S_i as a pipe*
        else $I \leftarrow I \cup S_i$ *// add each link as a pipe by itself*
return I

FIG. 7



$$\begin{bmatrix} & L_1 & L_2 & L_3 \\ e_1 - e_2 & 1 & 1 & 0 \\ e_1 - e_3 & 1 & 1 & 2 \\ e_2 - e_3 & 0 & 0 & 0 \end{bmatrix}$$

FIG. 8

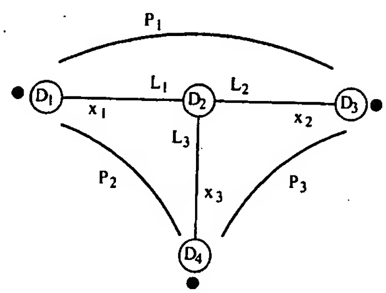


FIG. 9

Flow matrix 1

$$\begin{bmatrix} 1 & 1 & 0 \\ 1 & 0 & 1 \end{bmatrix}$$

Flow matrix 2

$$\begin{bmatrix} 1 & 1 & 0 \\ 1 & 0 & 1 \\ 0 & 1 & 1 \end{bmatrix}$$

FIG. 10

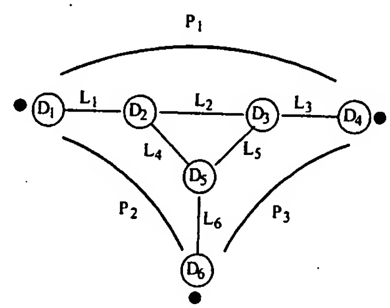


FIG. 11

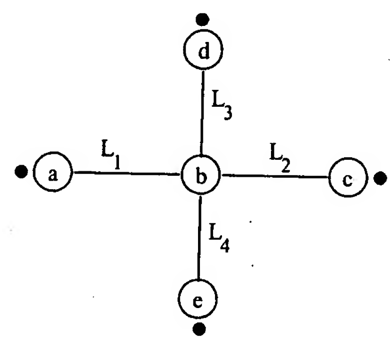


FIG. 12

	L_1	L_2	L_3	L_4
$L_1.L_4$	1	0	0	1
$L_4.L_2$	0	1	0	1
$L_2.L_3$	0	1	1	0
$L_3.L_1$	1	0	1	0

$\{L_1.L_4, L_4.L_2, L_2.L_3, L_3.L_1\}$

	L_1	L_2	L_3	L_4
$L_1.L_2$	1	1	0	0
$L_1.L_3$	1	0	1	0
$L_1.L_4$	1	0	0	1
$L_2.L_3$	0	1	1	0

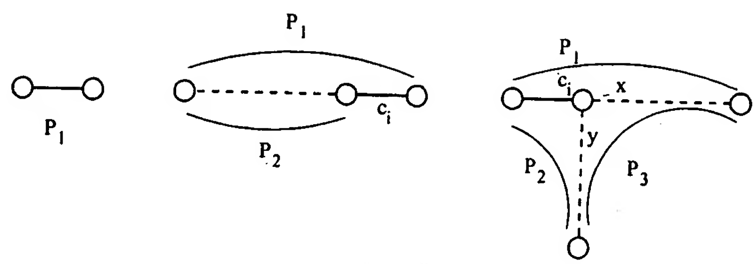
$\{L_1, L_2, L_3, L_4\}$

FIG. 13

Select_Matrix($G' = (D', I)$):Reduced Network Topology Graph, E: Set of Leaves)

```
W: Set of worms in G' wrt E, W ← ∅
R: Set of paths, R ← ∅
Compute P' for G' wrt E
open ← P'
while open ≠ ∅
    select p from open
    for each pipe c_i on p = c_1.c_2. ... .c_length(p)
        if ∃S ⊂ open such that S makes c_i estimable                          ← B1
            Compute S' which has the original value of each path in S
            R ← R ∪ S'
            W ← W ∪ {c_i}
            update open and W such that ∀p' ∈ open
                p' does not contain any estimable path in W      // c_i is removed from paths in open
        else
            c_{i+1} ← c_i.c_{i+1}
    open ← open \ {p}
return W, R
```

FIG. 14



$c_i = P_1$

Pattern 1

$P_2 \cdot c_i = P_1$

Pattern 2

$c_i \cdot x = P_1$
$c_i \cdot y = P_2$
$x \cdot y = P_3$

Pattern 3

FIG. 15

Compute_EstPaths($G' = (D', I)$:Reduced Network Topology Graph, E: Set of Leaves, P'_{t_i}: End-to-end paths at time t_i)

```
M: A Minimal set of estimable paths for G' wrt E, M ← ∅
open ← P'_{t_i}
while open ≠ ∅
    while open not converged
        select p from open
        for each pipe c_i on p = c_1.c_2. ... .c_{length(p)}
            if ∃S ⊂ open such that S makes c_i estimable
                M ← M ∪ {c_i}
                update open and M such that ∀p' ∈ open
                    p' does not contain any estimable path in M and        // c_i is removed from paths in open
                    open ← open \ {p}
        else
            abort processing of p
    if open ≠ ∅
        select shortest p in open
        open ← open \ {p}
        M ← M ∪ {p}
return M
```

FIG. 16